UCRL- 102659
PREPRINT

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To be published in the proceedings for
the workshop on "High Energy Astrophysics
for the 21st Century" sponsored by NASA and Los Alamos
Taos, New Mexico
December 11-12, 1989

January 3, 1990

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One of the most exciting recent development in black hole astrophysics is the discovery by the HEAO-3 experiment of transient enhanced MeV gamma ray emissions from Cygnus X-1 and the Galactic Center, and the potentially correlated appearance of the 511 keV annihilation line from the Galactic Center (Ling et al 1987, Riegler et al 1985). If these soft gamma ray bumps and annihilation lines can be proven to be universal signatures of black hole accretions, then they will provide a new window on the overall black hole phenomenon from stellar mass black holes to AGNs. Hence it is important for future high energy astrophysics space missions to incorporate the study of soft gamma emissions from black hole candidates as a major component of their scientific goals.

Fig. 1 reproduces the spectra of Cyg X-1 as detected by HEAO-3 in 1979-80. The MeV gamma ray bump is apparent only during the gamma-1 state lasting less than two weeks when the hard x-ray intensity is lowest (cf. Ling et al 1987). Note that the bump is extremely hard (photon spectral index ~ 0) with a very sharp cutoff above ~2 MeV. This is in contrast to the nonthermal power-law gamma ray tails reported for many compact objects and gamma ray bursts. It strongly hints at a thermal origin. To date, the most natural and simplest model for the emission of this bump is that proposed by Liang and Dermer (1988). This model invokes the swelling of the innermost accretion disk into a quasi-spherical pair-dominated hot cloud of temperature ~ mc^2 where m is the electron rest mass, and the bump is due to a combination of Comptonized bremsstrahlung and annihilation radiation. First principle calculations of the spectral output by Liang and Dermer (1988) show that the best fit cloud parameters are: radius ~ 300 km (~ 10 Schwarzschild radii for a 10 $M_\odot$ black hole), temperature ~ 0.8 mc^2, radial Thompson depth τ_T ~ 2, pair density $n_\pm \sim 10^{17} cm^{-3}$ and compactness (cf. Svensson 1984) $\ell \sim 12$.

The Galactic Center was observed in 1979 by HEAO-3 to have a similar behavior (Riegler et al 1985, Fig. 2). Using the same spectral modeling techniques Dermer and Liang (1990) find that the best fit cloud parameters are: radius ~ 5000 km (~16 Schwarzschild radii for a 100 $M_\odot$ black hole), temperature ~ 1.1 mc^2, radial Thompson depth ~ 1.5, and compactness $\ell \sim 8$ assuming a source distance of 8.5 kpc.

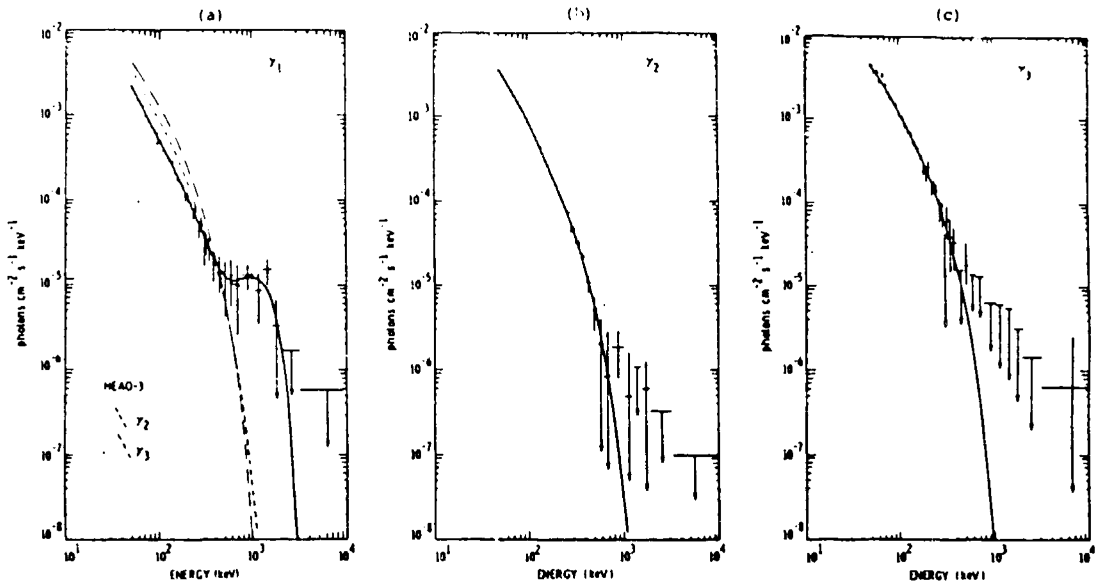

Fig. 1. HEAO-3 1979-80 spectra of Cyg X-1. Only the γ-1 state during which the hard x-ray intensity is superlow shows a strong MeV bump (from Ling et al. 1987).

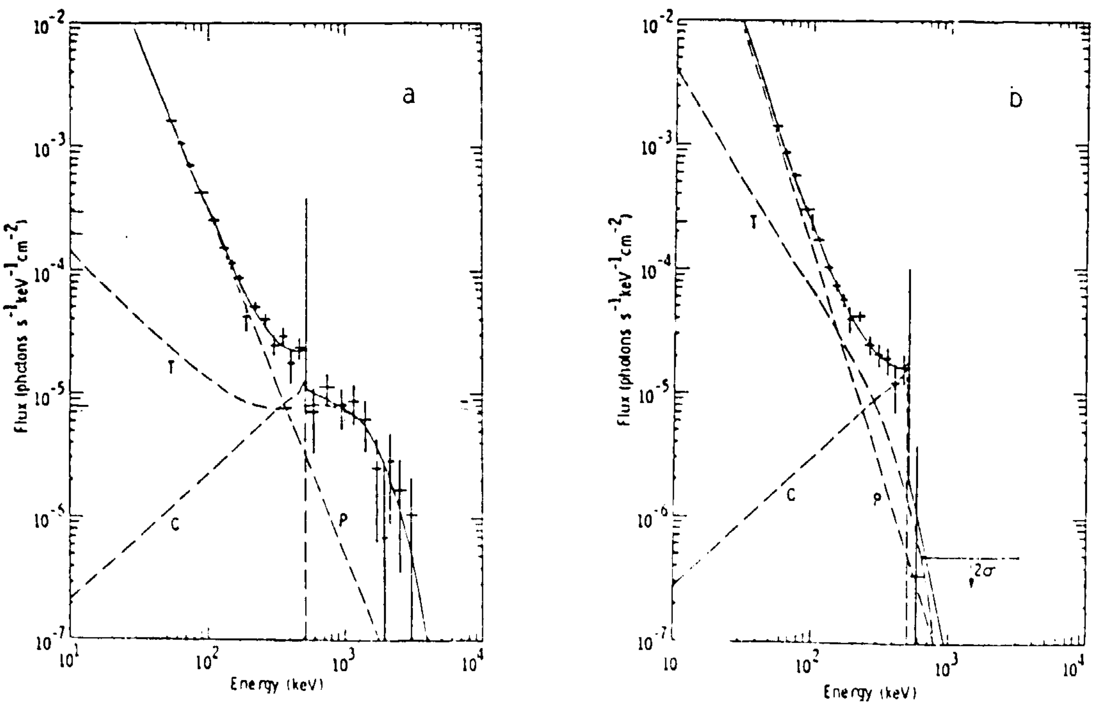

Fig. 2. HEAO-3 1979-80 spectra of the Galactic Center. Only the Fall 79 spectrum (a) shows a strong MeV bump with correlated increase in the 511 KeV line flux (from Riegler et al. 1985).

What could be causing the quiescent x ray disk emitting at tens of keV temperature (e.g. Steinle et al 1982) to heat up to a temperature of ~ mc^2 and produce a hard spectrum? Note that the lack of soft photons, whether external or internal synchrotron photons, is crucial to obtaining a hard spectrum. We speculate that the quenching of the soft photon source that normally cools the inner disk via inverse Compton (Shapiro et al 1976) is the culprit. A likely, but not necessarily unique scenario for the depletion of soft photons and the heating of the inner disk is recently suggested by Wandel and Liang (1989) in the context of AGNs but can be directly applied to Cyg X-1 and the Galactic Center. To understand this we have to go back to the model of Thorne and Price (1975) who postulate that the radiation pressure-dominated inner disk is unstable and can thicken up physically to become optically thin. It then cools via inverse Compton upscattering of soft photons from the external blackbody disk. This is the foundation of the Shapiro et al (1976) model. Wandel and Liang (1989) go one step further and show that if the Thorne-Price thinning radius moves further out to say, $\geq$ 50 Schwarschild radii, then the external soft photon will no longer penetrate the inner part of the disk, and the disk interior to, say 10 Schwarzschild radii, can only cool by Comptonized bremsstrahlung and pair production. First principle calculations show that indeed a relativistically hot cloud and an MeV spectral bump could result (Fig. 3). The exact temperature is regulated by the viscosity parameter. For Cyg X-1 and Galactic Center the derived viscosity $\bar{\alpha}$ lie in the range 0.1-0.01 (cf. Liang 1989). Since the magnetic field must be $\lesssim$ 1% of equipartition value in order for the synchrotron soft photons not to destroy the hard spectrum (Dermer 1989), we conclude that magnetic reconnection cannot be a major contributor to the azimuthal stress.

If we accept the thermal pair cloud picture as the correct baseline model, then MeV gamma ray observations can provide new clean diagnostics of black holes which x-ray observations fail to. Fig. 4 summarizes the direct observables and the derivable parameters of the hole and the inner accretion flow.

The thermal pair cloud model predicts a number of observational tests. The following is a list of some of the major ones:

a) Energy conservation requires that the gamma bump luminosity replaces the appropriate fraction of the quiescent x-ray luminosity. This can be tested by studying the pair temperature as a function of gamma to total luminosity ratio (Liang 1989).

b) Interaction of the gamma rays with the disk x-rays should produce an escaping pair wind, which may annihilate in the cool circumstellar or interstellar medium to produce a narrow

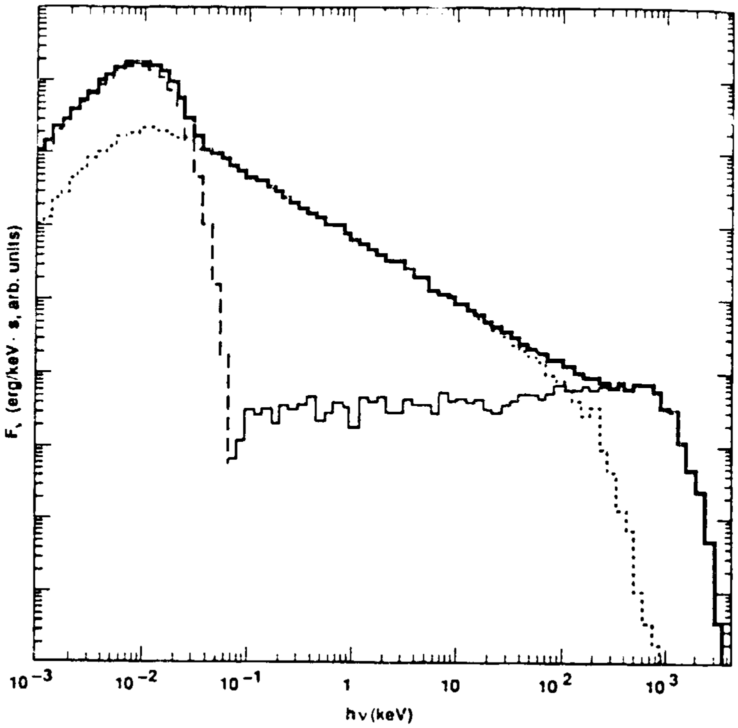

Fig. 3. Composite Monte Carlo model spectrum of a 10^8 $M_\odot$ AGN disk with the thinning radius at 100 GM/c^2. The disk interior to 20 GM/c^2 is not cooled by external soft photons and heats up to produce an MeV bump. Details see Wandel and Liang (1989).

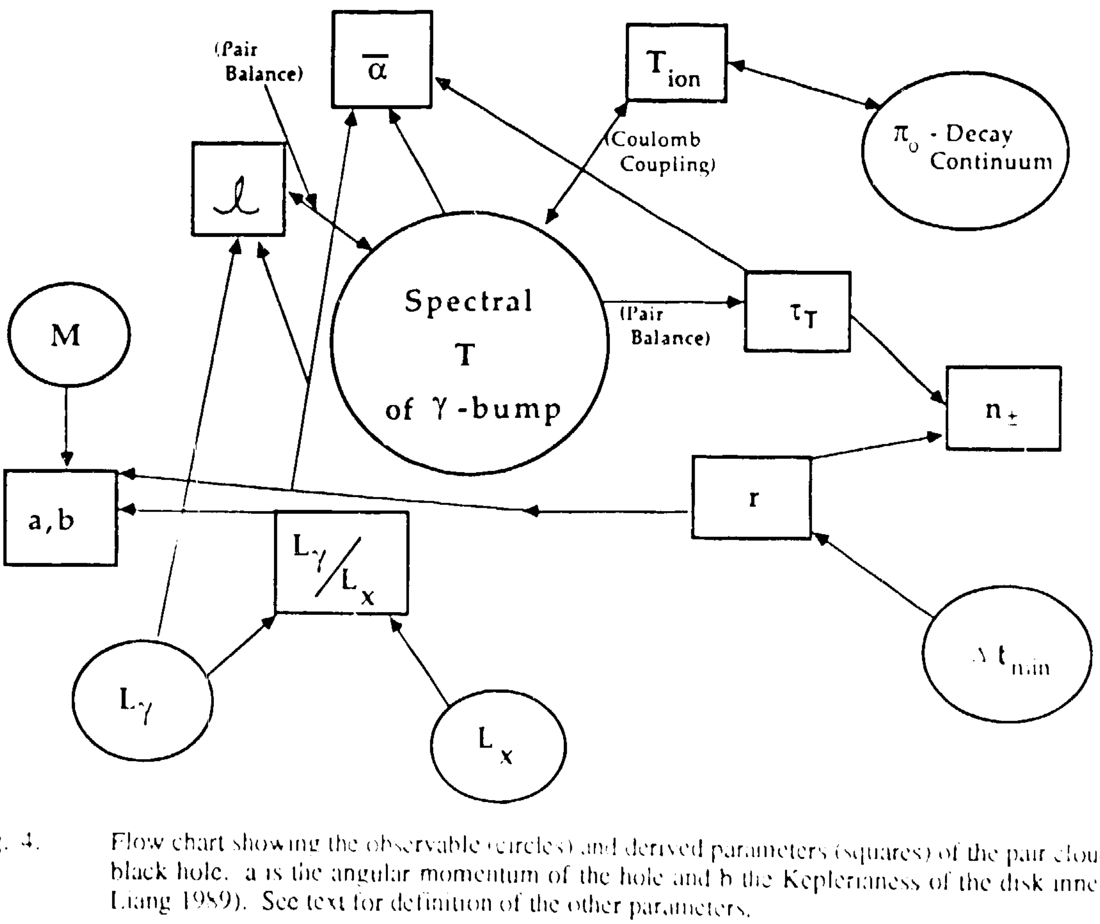

Fig. 4. Flow chart showing the observable (circles) and derived parameters (squares) of the pair cloud around a black hole. a is the angular momentum of the hole and b the Keplerianess of the disk inner edge (cf., Liang 1989). See text for definition of the other parameters.

511 keV line. This can be tested by observing the correlation of the narrow 511 line with the MeV continuum and measuring its absolute intensity (e.g. Lingenfelter and Ramaty 1989)

c) Based on the picture of Wandel and Liang (1989) we expect an anticorrelation between the intensity of the MeV gamma bump and the soft (UV or soft x-rays) continuum. Future simultaneous multiwavelength observations can test this.

d) If rapid time variability in gamma rays (say down to 10's of ms) can one day be measured, then the compactness of the source ~ $L/c\Delta t$ may become an observable. Its correlation or anti-correlation with temperature could provide a clean test of the theory of pair-balanced plasmas (Svensson 1984, Zdziarski 1984).

From the space observation points of view what are the near term priorities? We list a few objectives which should be achievable with observations by GRO and GRANAT:

a) The most important one is the confirmation of the MeV bump in Cyg X-1 and the Galactic Center with higher significance and spectral quality then that obtained by HEAO-3 and balloon flights, (e.g. Baker et al. 1973, McConnell et al. 1987) especially the details of the spectrum above ~ MeV.

b) Time profile for the rise and decay of the bump and its long term duty cycle.

c) Confirmation of the narrow 511 keV line and its time correlation with the MeV continuum.

d) Search for similar bumps in other prime black hole candidates, including A0620, LMC X-3, GX339-4, and the nearby AGNs brightest in the hard x-rays. The best time to look for this bump is when the hard x-rays is lowest.

e) Simultaneous multiwavelength observations from UV to gamma rays whenever an MeV excess is detected.

f) Search for the π_0-decay continuum near 70 MeV which may exist if the hot cloud ion temperature approaches the virial temperature of ~ 100 MeV (Dermer 1989).

g) Check on the gamma ray spectra of LMXB neutron stars to see if they might exhibit similar bumps. Based on the above thermal model we expect neutron stars not to exhibit such bumps due to the preponderance of soft x-rays from the central star. But if we find that neutron stars exhibit similar bumps than we can conclude that they are no longer a unique signature of black holes and the thermal pair cloud model must be revised.

What are the future challenges, especially observations requiring new technologies projected for the XXIst century? One obvious major challenge is the measurement of rapid time variability down to say the natural time scales of the inner region of the accretion flow. For Cyg X-1 type masses these are 3-30 ms. Let us say we want to detect at least 10 photons of the MeV continuum over a 1 (10) ms integration time. The flux of Fig. 1 says that we need a detector area of at least 10^6 (10^5)cm^2. This is far-fetched for now but conceivable for a space station or lunar base platform. The time resolution requirement scales inversely with the mass of the hole. Hence for the Galactic Center (say 100 $M_\odot$) the required detector area would be ten times smaller, etc. Detection of the narrow 511 keV line from Cyg X-1 is expected to be feasible for GRO (cf. Dermer and Liang 1988), but for other sources we would probably need at least the NAE sensitivity or better. Also GRO would not be able to resolve the line profile which would tell us much about the annihilation site. Even the ~ 1 keV resolution at 511 keV projected for NAE would not be able to distinguish between a cold ISM versus a warm (10^4 K) circumstellar wind. We would like to get down to ~ 100 eV spectral resolution at 511 keV in the XXIst century if possible. High spatial resolution ($\lesssim$ arc min) imaging of the Galactic Center region both in hard x-rays and gamma rays is also needed to separate out the absolute contribution of different sources. Finally, gamma ray polarization measurement poses another useful challenge for the future. A detection of even ~ 1% linear polarization in the MeV continuum would cast strong doubt on the quasi-spherical geometry picture.

This work was performed under the auspices of the U.S. DOE by the Lawrence Livermore National Laboratory under contract #W-7405-ENG-48. and at Stanford this work is partially supported by NASA grant NGR 05-020-668.

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